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Assessment of the habitat quality of the threatened butterfly, *Zizina emelina* (Lepidoptera, Lycaenidae) in the agro-ecosystem of Japan and implications for conservation

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Abstract We assessed habitat quality of *Zizina emelina*, a threatened butterfly in Japan, in the farmlands of Kamogawa City, Chiba Prefecture, in central Japan. We established five 50 m census routes at three sites, ridges where weeds are mowed only in spring (hereafter, ridges mowed only in spring), ridges where weeds are mowed every month after spring (hereafter, ridges mowed every month) and meadow of *Trifolium repens* to count the adult *Z. emelina* along each route. On the ridges mowed only in spring and the ridges mowed every month, there were no significant differences in the number of adult *Z. emelina* individuals during the period from early April to late June between the two ridges. However, during the period from late June to early September, the number of adults on the ridges mowed only in spring was significantly higher than that on the ridges mowed in every month. During the period from early September to late October, the number of adults tended to increase on the ridges mowed every month, and decrease on those mowed only in spring; as a result, no significant differences were detected in the number of adults between the ridges. In a meadow of *Trifolium repens*, the adult emergence period was from late August to late October, and the peak in the number of adults was in late September. The synthetic dominance of *Lotus japonicus*, the larval host plant of *Z. emelina*, was high at the lower part of both ridges mowed only in spring and those mowed every month, and at both sides of a non-paved footpath present around paddy fields. On the ridges mowed only in spring, the synthetic dominance of *L. japonicus* declined from May to October, while on the ridges mowed every month, it declined from May to August, and went up from August to September. This suggests that the synthetic dominance of *L. japonicus* contributed much to the increase in the number of adults during the period from mid August to early October on the ridges mowed in every month. From these results, it is suggested that, in order to retain a high density of *Z. emelina* and the predominance of *L. japonicus* in agro-ecosystems, it is important that a mixture of both ridges that are mowed both in spring and every month is established in their habitats. Since we observed eggs and larvae of *Z. emelina* on *T. repens* in the meadow habitat of this study, a meadow habitat is also thought to be important for conservation of *Z. emelina*.

Key words *Zizina emelina*, mowing, agro-ecosystems, maintenance of population, conservation.

Introduction

In recent years, keeping a perspective on biodiversity conservation has been important for the design of world agro-ecosystems. In particular, it is very important to establish appropriate management techniques (Kiritani, 2004). To this end, it is necessary to assess the

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habitat quality of the organisms living in the agro-ecosystem and clarify the optimal habitat conditions for conserving them.

Among insects, water bugs, diving beetles and butterflies are superior organisms for analyzing the suitability of habitats due to their relatively large body sizes and conspicuousness, which make it easy to identify and count them in the field. Until the present, assessment of habitat quality in agro-ecosystems, has been mainly conducted for aquatic insects in Japan (Saijou, 2001, 2002; Mukai *et al.*, 2005; Mukai and Ishii, 2007). With regard to butterflies, assessment of habitat quality has been conducted for grassland species (*e. g.* Thomas and Harrison, 1992; Thomas *et al.*, 1992; Thomas and Jones, 1993; Hill *et al.*, 1996; Krauss *et al.*, 2004; Fowles and Smith, 2006; Liu *et al.*, 2006; Schmitt *et al.*, 2006; Cassel-Lundhagen and Sjögren-Gulve, 2007; Louy et al., 2007; Schtickzelle *et al.*, 2007) and tree-dwelling butterflies in woodland regions (Greatorex-Davies *et al.*, 1992; Bergman, 2001; Cizek and Konvicka, 2005; Kobayashi and Kitahara, 2005; Konvicka *et al.*, 2005; Freese *et al.*, 2006; Li *et al.*, 2006; Konvicka *et al.*, 2008; Kobayashi *et al.*, 2008). However, little attempt has yet been made to assess the habitat quality of butterflies living in human managed biotopes of an agro-ecosystem.

In Japan, *Zizina emelina* (Lepidoptera: Lycaenidae) usually lives in and around the community of *Lotus japonicus* which grows temporarily on the flood plain of a river, and this plant is also the main larval host plant of this butterfly (Fukuda *et al.*, 1984). *Z. emelina* also inhabits short grasslands mowed by human beings, for example, the community of *L. japonicus* which grows on the ridges around cultivated fields in an agro-ecosystem (Fukuda *et al.*, 1984), and the community of *Trifolium repens* which grows in meadow areas in agroecosystems, artificial banks, and grassy places along the side of airfield runways. However, in recent years, the population density of *Z. emelina* has been declining in farmland and river floodplains habitats. Thus, this butterfly species is now ranked as a threatened species I (CR+EN) in the Red Data book of Japan (Ministry of the Environment, 2006).

In the present study, we selected farmland in Kamogawa City, Chiba Prefecture, in central Japan as the study area. In this area, there are various types of habitats of *Z. emelina*, such as meadows dominated by *T. repens*, ridges where weeds including *L. japonica* are mowed only in March and April facing fallow fields (hereafter, ridges mowed only in spring), and ridges where weeds including *L. japonica* are mowed in every month from March to October facing paddy fields to avoid shading the paddies (hereafter, ridges mowed every month). However, no attempts have yet been made to assess the habitat quality of *Z. emelina* living in the respective biotopes of the farmland. In this study, we aimed to assess the habitat quality of *Z. emelina* populations living in various types of agro-biotopes, and based on the results, to discuss a conservation strategy for the species. For the analyses, we examined the population density of *Z. emelina* and the dominance of its host plant, *L. japonicus* in each agro-biotope stated above.

Life history of *Zizina emelina*

In central Japan, *Z. emelina* overwinters in the larval stage. On the Kanto Plain of central Japan, the flight season of adults extends from early April to early November, and the number of generations per year is usually 4 or 5 (Fukuda *et al.*,1984). *L. japonicus* is the main larval host plant, but *Indigofera pseudo-tinctoria, Kummerowia striata, Medicago lupulina*, and *T. repens* are also known to be host plants of *Z. emelina*.

Study area

This study was done on the ridges of a paddy field and meadow dominated by *T. repens*, in

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Kamogawa City, Chiba Prefecture, central Japan (Fig. 1). The investigation was done at the following three sites:

(1) Ridges facing a fallow field mowed only in spring

The weeds including *L. japonica* on the ridges were mowed once in March and once in April. The cuttings were removed from the ridges. For this study, mowing was not done from May onwards.

(2) Ridges facing a paddy field mowed in every month

The weeds including *L. japonica* on the ridges were mowed once a month from March to October. The cuttings were removed from the ridges.

(3)Meadow of *T. repens*

T. repens was widely cultivated in the meadow. *T. repens* was mowed once every two months from April to October. The cuttings were removed from the meadow, and used as feed for cattle.

Materials and methods

Monitoring the number of adults

We established five 50 m census routes at each of sites (1)–(3) stated above, and counted the adult *Z. emelina* along each route by transect counts (*e. g.* Pollard, 1977; Thomas, 1983; Yamamoto, 1988; Ishii, 1993; Pollard and Yates, 1993). At that time, nectar plants utilized by the adults were also recorded. The transect counts were made five times a month from 10: 00 to 13: 00 on days with fine or cloudy weather during the period from April to October in 2005 and 2006. The interval between each day of transect count was four to

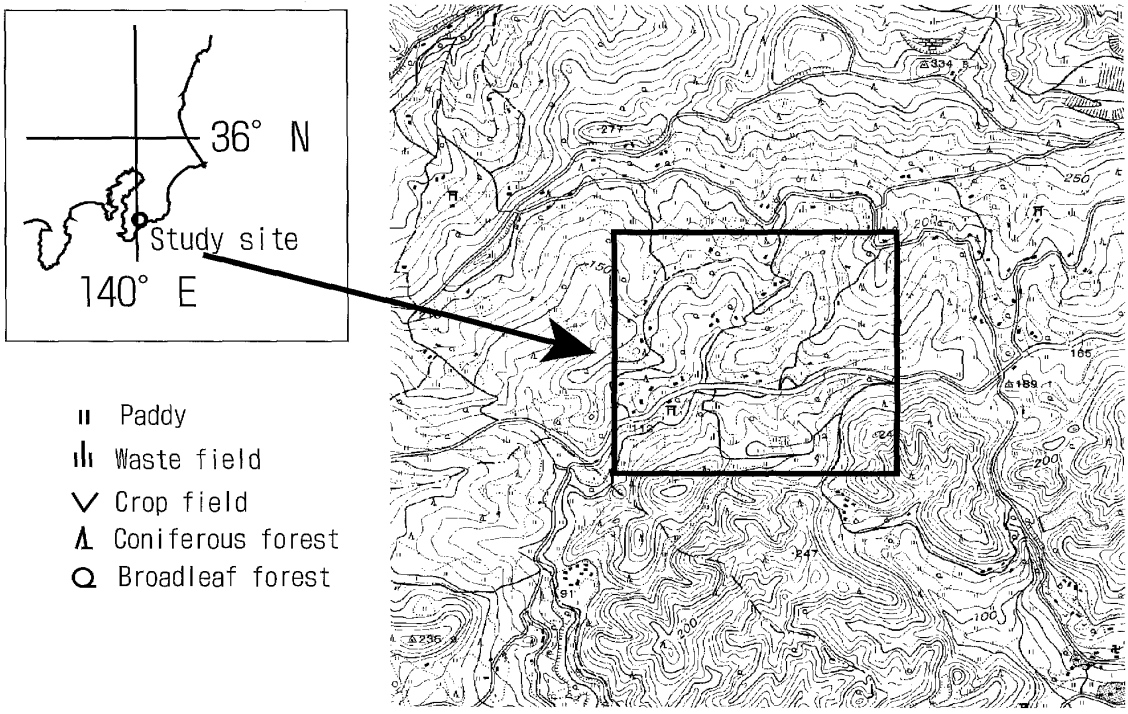

Fig. 1. This research was done in Kamogawa City, Chiba Prefecture.

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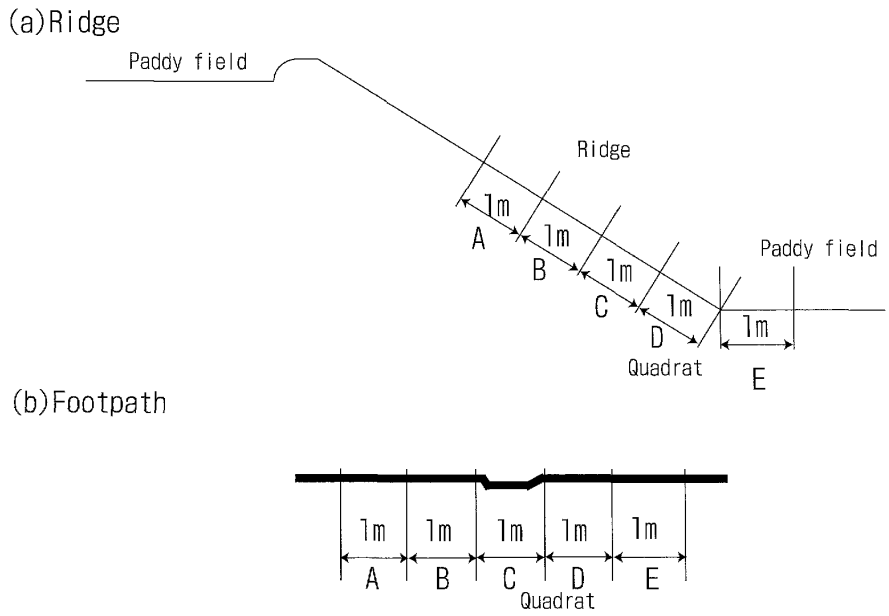

Fig. 2. The installation method of the quadrat for investigating the dominance of *Lotus japonicus*. Five 1×1 m quadrats were arranged on the slope of ridges, and alongside a foot path.

nine days. In the study area, since it was difficult to identify *Z. emelina*, *Pseudozizeeria maha* and *Everes argiades* by sight because of their similar characteristics, we captured all individuals observed with an insect net, and released them at the place captured after identification.

Dominance of *L. japonicus*

We established quadrats to examine the dominance of *L. japonicus* on the ridges mowed only in spring and once a month and unpaved footpaths alongside the paddy fields that were less than 1 m in width and mowed only in spring and once a month. On the ridges, we established five connected 1×1 m quadrats named A, B, C, D, and E on the slope of the ridges as shown in Fig. 2, and regarded these as one set of quadrats. We established five and three sets of quadrats on the ridges mowed only in spring and once a month, respectively. Along the footpath, we established five connected 1×1 m quadrats named A, B, C, D, and E in the center (one quadrat) and on both sides (two quadrats) of the footpath as shown in Fig. 2, and regarded these as one set of quadrats. We established four and two sets of quadrats on the footpaths mowed only in spring and once a month, respectively.

Coverage rate was defined as the rate of the part of a sample area covered by a particular plant species in a quadrat (Braun-Blanquet, 1964). First, we examined class of dominance (*i. e.* +, r, 1, 2, 3, 4, 5) of *Miscanthus sinensis*, which is the dominant species on ridges, and *L. japonicus* in each quadrat once a month from May to October in 2005 and 2006. Second, we determined the percentage of dominance of each species based on the class of dominance, as shown in Table 1. Third, we calculated the synthetic dominance of each plant species each month using the following equation based on the percentage of dominance.

Synthetic dominance=(The sum of the percentage of the dominance in all quadrats of the species (%)×100)/The number of all quadrats (Braun-Blanquet, 1964)

In addition, we calculated the annual average of the synthetic dominance of *L. japonicus* in the quadrats of A, B, C, D, and E on all ridges mowed only in spring and those mowed

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Table 1. Class of dominance and percentage of dominance.

Class of dominance	The basis of a judgment	Percentage of dominance (%)
5	"Coverage rate is larger than 3/4, the number of individuals is arbitrary."	87.5 (%)
4	"Coverage rate is 3/4 from 1/2, the number of individuals is arbitrary."	62.5 (%)
3	"Coverage rate is 1/2 from 1/4, the number of individuals is arbitrary."	37.5 (%)
2	"Coverage rate is 1/10 to 1/4 or, there are very many individuals."	17.5 (%)
1	"Coverage rate is small although there are many individuals, or although coverage rate is large although individuals are grown sparsely. (Coverage rate is less than 1/10)"	5.0 (%)
+	Object kind grows sparsely and coverage rate is very small.	0.1 (%)
r	Object kind grows independently.	0.1 (%)

every month, and all footpaths mowed only in spring and in every month.

Further, we measured the height of the grass community at five randomly sampled spots in each of quadrats A, B, C, D, and E on all ridges mowed only in spring and those mowed every month, and all footpaths mowed only in spring and once a month from May to October, and calculated the annual average.

Statistical analysis

A Wilcoxon signed-ranks test was used to compare the number of *Z. emelina* between the ridges mowed only in spring and those mowed every month (STATISTICA 2000, StatSoft, Inc.). A Kruskal-Wallis test was used to compare the number of *Z. emelina* among the ridges mowed only in spring, those mowed every month, and the meadow dominated by *T. repenswas* (STATISTICA 2000, StatSoft, Inc.).

Results

Adult abundance

In both 2005 and 2006, *Z. emelina* were observed during the period from early April to late October on both ridges mowed only in spring and those mowed every month, while in the meadow, they were observed only from mid August to late October (Fig. 3).

In 2005, the average number of individuals per day was 3.89, 2.57, 1.20 on the ridges mowed only in spring, those mowed every month and in the meadow, respectively. In 2005, there was a significant difference in the number of adults during the whole of a survey period between the ridges mowed only in spring and those mowed every month (Table 2). In 2006, the average number of adults per day was 2.03, 1.37 and 0.74 on the ridges mowed only in spring, those mowed every month, and in the meadow, respectively. In 2006, there was a significant difference in the number of adults during the whole of a survey period between ridges mowed only in spring and those mowed every month (Table 2).

In both years, there were five peaks (*i. e.* from mid April to early May (Fig. 3a), late May to early June (Fig. 3b), late June to mid July (Fig. 3c), early August to late August (Fig. 3d), and mid September to early October (Fig. 3e)) in the number of adults observed both on the ridges mowed only in spring and those mowed every month.

In both 2005 and 2006, there were no significant differences in the number of adults during the period from early April to mid June (corresponding to Figs 3a and b) between the ridges mowed only in spring and those mowed every month, whereas during the period from late June to early September (corresponding to Figs 3c and d), the number of adults was

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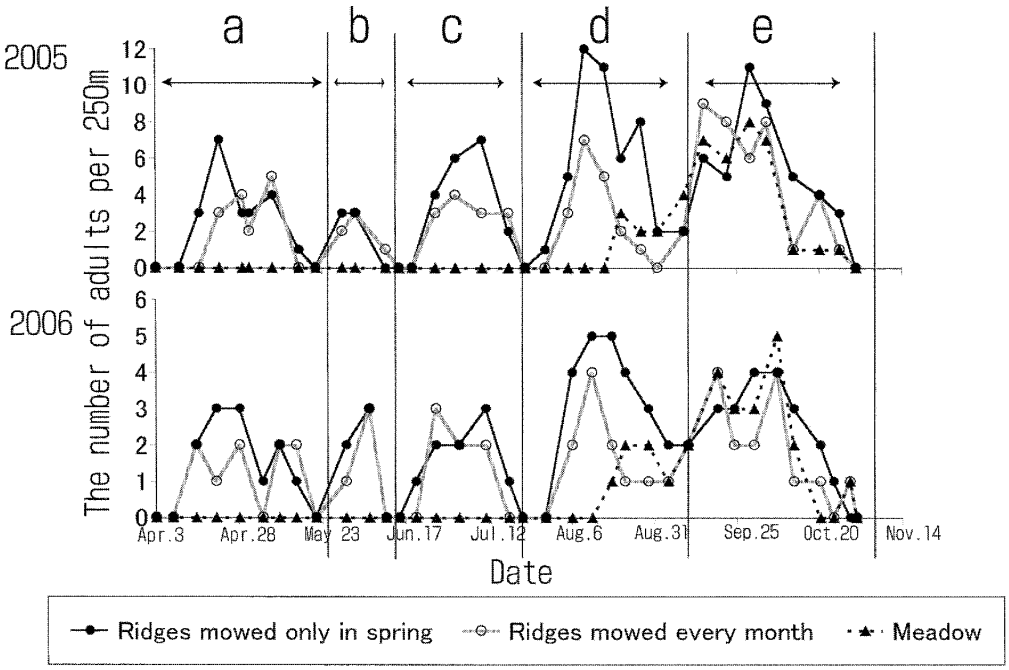

Fig. 3. Seasonal fluctuations of the population of adult *Zizina emelina* in 2005 and 2006. In both years, there were five peaks (*i. e.* from mid April to early May (a), late May to early June (b), late June to mid July (c), early August to late August (d), and mid September to early October (e)) in the number of adults observed both on the ridges mowed only those mowed in every month.

significantly greater on the ridges mowed only in spring than on those mowed every month. In both years many eggs of *Z. emelina* were found on the part of *L. japonicus* mowed on the ridges mowed in every month.

In both years, the adults were most abundant in mid-August, and mid-, and late September on the ridges mowed every month, whilst the number of adults in late September became slightly less than mid-August on the ridges mowed only in spring. In addition, during the period from early September to late October, a high synthetic dominance of M. sinensis was observed in places on the transect route established on the ridges mowed only in spring. In such places, the dominance of *L. japonicus* was low and *Z. emelina* adults were not ob-

Table 2. Average number of Zizina emelina at mowed ridge only in spring and in every month.

	Mowed ridge only in spring	Mowed ridge only in every month	$P^{1)}$
2005			
The whole of a survey period	3.89±3.43	2.57±2.63	"Z=2.92, P<0.01"
From April 3 to June 19	1.93±2.13	1.43±1.74	"Z=1.05, P=0.29"
From June 26 to September 1	5.33±3.80	2.85±2.15	"Z=2.76, P<0.01"
From September 9 to October 31	5.11±3.22	4.33±3.50	"Z=0.73, P=0.46"
2006			
The whole of a survey period	2.03±1.54	1.37±1.24	"Z=3.07, P<0.01"
From April 3 to June 20	1.29±1.66	0.93±1.03	"Z=1.57, P=0.12"
From June 26 to September 4	2.58±3.80	1.50±1.19	"Z=2.31, P<0.05"
From September 10 to October 29	2.44±1.26	1.89±1.29	"Z=1.35, P=0.18"

[1)]Wilcoxon signed-ranks test.

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served. As a result, there were no significant differences in the number of adults between both ridges during the period from early September to late October (corresponding to Fig. 3e).

In both 2005 and 2006, adult *Z. emelina* were found from the end of August in the meadow, and the number of adults reached a peak late in September, and decreased thereafter (Fig. 3). During the period in the meadow, we observed eggs and larvae of *Z. emelina* on *T. repens*. In 2005, the average number of *Z. emelina* adults on the ridges mowed only in spring, those mowed every month, and the meadow dominated by *T. repens* was 5.55, 3.82, and 3.82, respectively, during the period from August 21 to October 26, which corresponded to the adult flight period in the meadow, and thus, there were no significant differences in the number of adults among these three study sites (Kruskal-Wallis test, χ^2=2.69, P=0.26). Also in 2006, the average number of *Z. emelina* adults on the ridges mowed only in spring, on those mowed every month, and in the meadow dominated by *T. repens* was 2.77, 1.69, and 2.00, respectively during the period from August 18 to October 29, which corresponded to the adult flight period in the meadow, and thus, there were no significant differences in the numbers of adults among the three study sites (Kruskal-Wallis test, χ^2=4.69, P=0.10).

In this study, all nectar plants utilized by adults were *L. japonicus, T. repens, I. pseudo-tinctoria, Persicaria thunbergii, Trifolium pretense, Picris hieracioides* subsp. *japonica, Taraxacum officinale* Weber, *Ranunculus silerifolius, Justicia procumbens, Pueraria lobata* and *Hypochoeris radicata*. Among these species, *L. japonicus*, which is also a larval host plant, was most frequently utilized by the adults of *Z. emelina*, which used its flowers as a nectar resource.

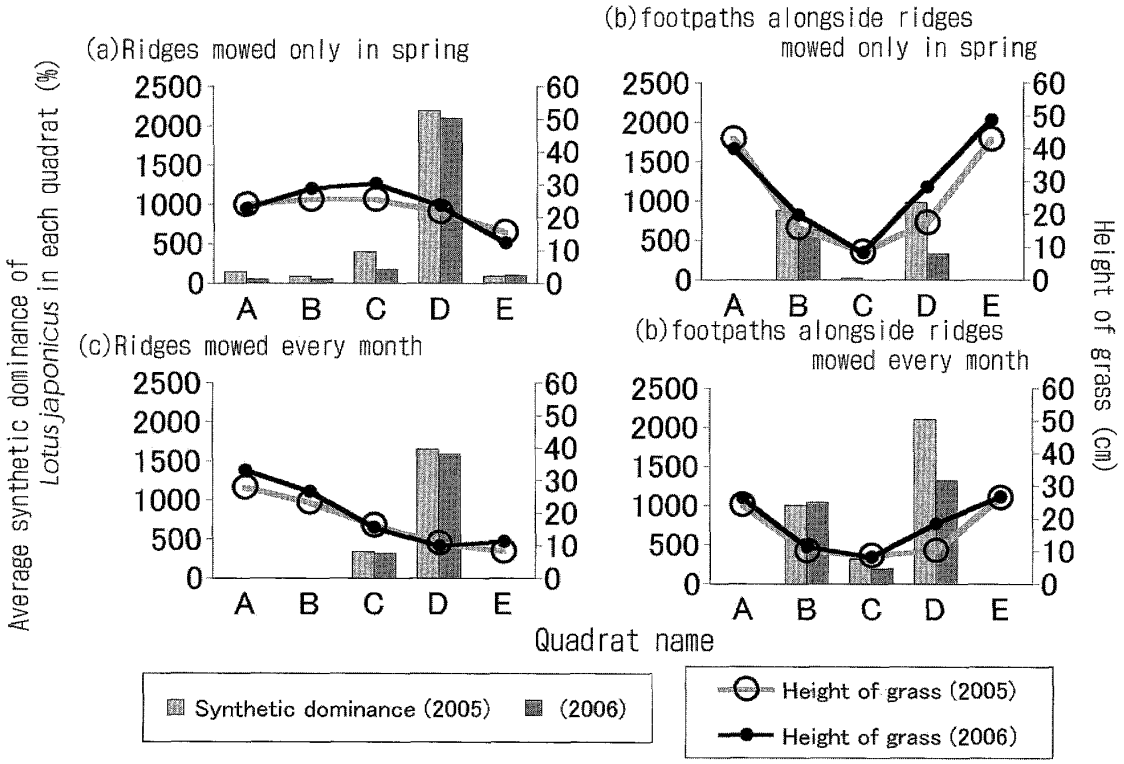

Fig. 4. The average synthetic dominance of *Lotus japonicus* in each quadrat in 2005 and 2006 and the height of the grass community in each quadrat.

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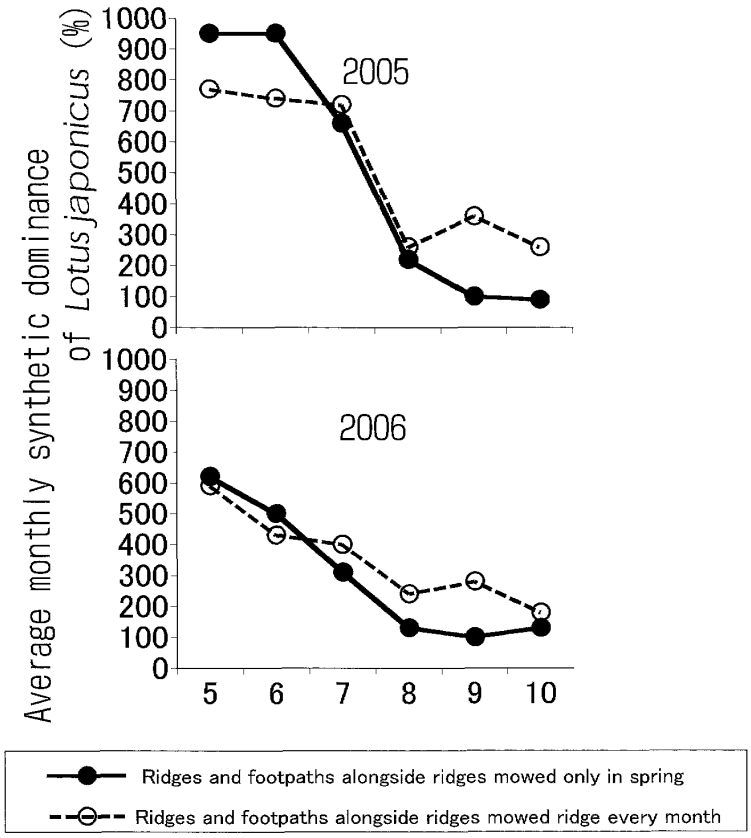

Fig. 5. Monthly fluctuation of the average synthetic dominance of *Lotus japonicus* in all the quadrats in 2005 and 2006.

Dominance of *L. japonicus*

Synthetic dominance of *L. japonicus* in quadrats A–E

In both years 2005 and 2006, the synthetic dominance of *L. japonicus* was the highest in quadrat D at the lower part of the ridges, and low in other quadrats on both the ridges mowed only in spring and on those mowed every month (Fig. 4), while the height of the grass community in quadrat D was lower than that in quadrats A, B, and C (Fig. 4).

In both years 2005 and 2006, the synthetic dominance of *L. japonicus* was high in quadrats B and D, followed by quadrat C, and no *L. japonicus* were found in quadrats A and E either on the footpaths mowed in spring or those mowed every month (Fig. 4). On the other hand, the height of grass community was lowest in quadrat C, followed by quadrats B and D, and it was highest in quadrats A and E (Fig. 4).

Seasonal fluctuations in the synthetic dominance of *L. japonicus* and *M. sinensis*

In both 2005 and 2006, on ridges and footpaths mowed only in spring, the synthetic dominance of *L. japonicus* declined from May to October (Fig. 5), while on the ridges and footpaths mowed every month, the synthetic dominance of *L. japonicus* declined from May until August, but went up from August to September (Fig. 5). On the whole, the synthetic dominance of *L. japonicus* was roughly higher on the ridges and footpaths mowed only in spring during the first half of the study period than on those mowed every month, but the synthetic dominance was higher on the ridges and footpaths mowed every month than on

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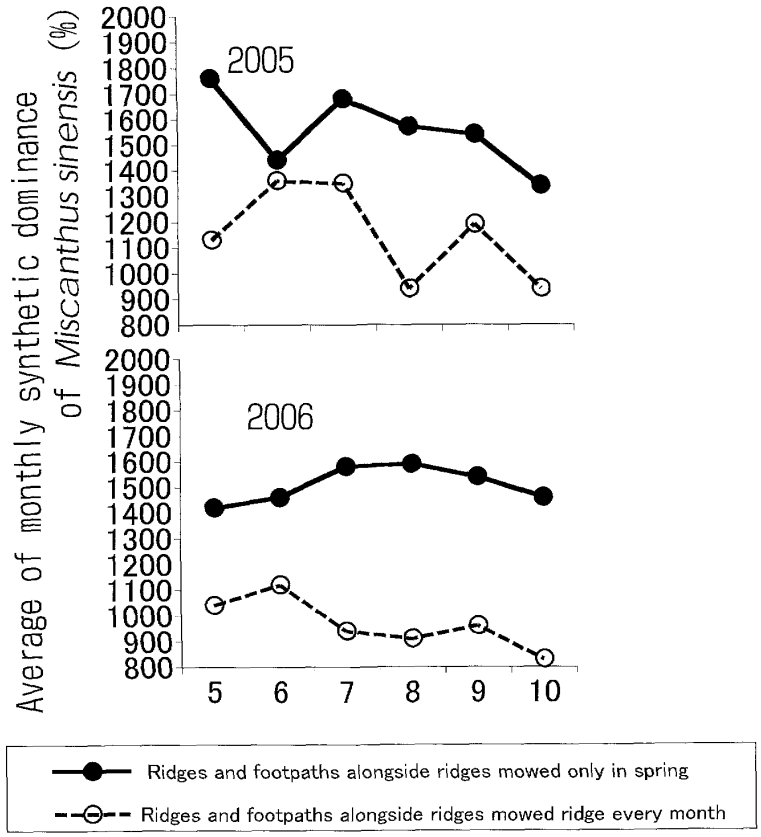

Fig. 6. Monthly fluctuation of the average synthetic dominance in all quadrats of *Miscanthus sinensis* in 2005 and 2006.

those mowed only in spring in the second half of the period (Fig. 5).

In both 2005 and 2006, the dominance of *M. sinensis* was higher on the ridges and footpaths mowed only in spring than on those mowed every month during the period from May to October (Fig. 6).

Discussion

Relation between mowing on ridges and the density of *Z. emelina*

In the present study, it is suggested that the abundance of *Z. emelina* was largely influenced by the activity of mowing in its habitat. The monthly mowing during the period from late June to early September apparently caused a decrease in the abundance of *Z. emelina*. This may be due to the removal *L. japonicus* with the eggs and larvae of *Z. emelina* and/or with the flowers as an important nectar resource of the adults by the frequent mowing. Indeed, we found many eggs on *L. japonicus* mowed at this time.

On the other hand, the fact that, on the ridges mowed every month, the number of *Z. emelina* adults during the period from early September to late October was higher than the other periods suggests that the monthly mowing attempts during this period enhanced or maintained the density of *Z. emelina*. The present study showed that the synthetic dominance of *L. japonicus* was roughly higher on the ridges and footpaths mowed only in spring during the first half of the study period, but synthetic dominance was higher on those mowed every

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month than on those mowed only in spring in the second half of the period. Therefore, it is suggested that the highest abundance of *Z. emelina* during the period from late August to late October on the ridges and foot paths mowed every month is intimately related to the enhancement of the dominance of *L. japonicus* through the influence of monthly mowing during the period. In contrast, on the ridges mowed only in spring, the synthetic dominance of *M. sinensis* was higher than on those mowed every month throughout the study period. This suggests that the lower dominance of *L. japonicus* during the second half of the study period on the ridges mowed only in spring was mainly caused by the increase in the biomass of *M. sinensis* that was probably due to the absence of mowing management.

Effects of mowing on ridges on growth of *L. japonicus*

The results of the quadrat study suggest that the habitat quality of *L. japonicus* was high on the lower parts of ridges and along the agricultural footpaths on both side of ridges. These places were close to cultivated areas or footpaths, and thus were probably those most strongly and closely cut by mowing management. This suggests that mowing management is advantageous for regeneration of *L. japonicus*.

Conservation implications

From our results, it is suggested that, in order to maintain the high density of *Z. emelina* populations, and the communities of the host plants, *L. japonicus*, we should mow weeds once a month in March and April, and then, there should be a coexistence of ridges mowed and those not mowed in the following every month. In fact, since no mowing seems to have negative effects on the cultivation of crops, it is desirable that no mowing management after April is conducted on ridges facing fallow fields. However, unfortunately in this study, we were not able to experimentally establish ridges mowed only in the summer season when the dominance of *L. japonicus* declines. Thus, further studies are needed to understand more effective conservation action plans for maintenance of both the butterfly and its host plant populations.

In addition, our study also suggested that meadow dominated by *T. repens* is important for conservation of *Z. emelina*, because, in this habitat, *Z. emelina* adults were observed during the period from mid-August to late October, and the population level was similar to that on the ridges during this period. In addition, eggs and larvae were observed on *T. repens*. However, further studies are needed to clarify the reason for the absence of *Z. emelina* adults during the period from spring to summer seasons, and to understand the importance of the meadow habitats for conservation of *Z. emelina* population.

In Japan, degradation of agro-ecosystems has been in progress recently due to the decline of farmers and/or its aging society. Also in the present study area, incidence of the fallow of paddy fields and the abandonment of management on the ridges have been recently increasing mainly due to the decline of farmers. Thus, it is predicted that, if this situation continues in this area, the populations of *Z. emelina* will become extinct. We emphasize that, in order to maintain the present *Z. emelina* populations in this area, the type of consistent mowing management demonstrated in the present study is needed from now on. In addition, it is suggested that mowing management revealed in this study might be applicable to the conservation of organisms living in a habitat of lawn grass prairie maintaained by frequent mowing in every year.

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摘　　要

農地におけるシルビアシジミの生息適地の解析と保全 (小林隆人・北原正彦・鈴木雄太・立川周二)

中部日本の千葉県鴨川市の農地において, シルビアシジミ *Zizina emelina* の生息適地の解析を行った. 私達は, 春季のみ雑草の刈り払いが行われる畦畔 (春季のみ刈り払いの畦畔) と春季以降毎月雑草の刈り払いが行われる畦畔 (毎月刈り払いの畦畔) および, 牧草地に成虫個体数を調べるルートを設置した. 春季のみ刈り払いの畦畔と毎月刈り払いの畦畔の成虫の個体数の間には4月初めから6月下旬にかけては有意な差は見られなかったが, 6月下旬から9月初めまでは春季刈り払いの畦畔において成虫の個体数が最も多くなり, この期間は春季刈り払いの畦畔の個体数の方が毎月刈り払いの畦畔よりも有意に多くなった. しかし, 9月の初めから10月下旬にかけては毎月刈り払いの畦畔において成虫の個体数は増加傾向であったのに対し, 春季刈り払いの畦畔における個体数は減少し, 両者の成虫の個体数の間に有意な差が見られなくなった. 牧草地では8月下旬から本種が確認されるようになり, 9月下旬にピークを迎え, その後は減少していった. 本種の幼虫の食草であるミヤコグサの総合優占度は, 春季のみ刈り払いおよび毎月刈り払いの両方の畦畔の下端部と田畑周囲の未舗装の歩道の両脇で高かった. 春季のみ刈り払いの畦畔においては, ミヤコグサは5月から10月にかけて総合優先度が低下していった. これに対し, 毎月刈り払いの畦畔では5月から8月までは総合優占度が低下したが, 8月から9月にかけては上昇し, このことが毎月刈りの払いの畦畔における8月中旬から10月上旬までのシルビアシジミの密度の増加傾向に寄与していることが示唆された. 以上の結果より, 農地においてシルビアシジミの密度とその食草であるミヤコグサの優占度を高く保つには, 春季刈り払いの畦畔と毎月刈り払いの畦畔を共存させることが望ましいと思われる. 今回の研究では, シロツメクサの牧草地では, 8月中旬から9月中旬までしかシルビアシジミの成虫を確認できなかった. この理由を明らかにすることはできなかったが, シロツメクサにおいて産卵や幼虫も確認されたのでシロツメクサの牧草地も本種の保全にとって必要であると考えられた.

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